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RESEARCH MEMORANDUM

LANDING CONDITIONS FOR LARGE AIRPLANES IN ROUTINE OPERATIONS

By Norman S. Silsby and Eziaslav N. Harrin

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

Measurements have been obtained by means of a specially developed photographic method of landing contact conditions of some commercial transports, the Boeing KC-97 tanker, the Boeing B-47 jet bomber, and the Convair B-36 bomber. From these measurements, vertical velocities and airspeeds at contact have been evaluated and a brief statistical analysis of the results, including the effect of horizontal gusts on the landing conditions for the transports, has been made.

The analysis indicates that one out of 1,000 landings will equal or exceed a vertical velocity of 3.5 fps and 4.7 fps for the nongusty and gusty conditions, respectively, or an increase of about 25 percent due to gustiness. It appears likely, however, that on the average the curves for the condition without gusts represents the more probable condition. The relative frequency of occurrence of gusts to no gusts was found to be 1 to 20 for a 5-year period at the Langley Air Force Base.

The values of vertical velocity likely to be equaled or exceeded once in 1,000 landings of routine operations of tankers and bombers were 5.5 fps for the KC-97 tankers, 6 fps for the B-47 jet bombers, and 7 fps for the B-36 bombers. These results are comparable to the transport probability curve for the condition without gusts, which indicated that an average vertical velocity for all transports of about 3.5 fps would be equaled or exceeded once in 1,000 landings.

The analysis of airspeed at contact indicated that one out of 1,000 landings will equal or exceed an airspeed of 50 percent above the stall for the B-36 airplane, 60 percent above the stall for the transports, and about 70 percent above the stall for the B-47 airplane.

INTRODUCTION

In order to aid in the development of more rational landing-loads design requirements and procedures, the National Advisory Committee for Aeronautics has been conducting a project to obtain statistical measurements of landing contact conditions for various types of airplanes during routine daytime operations. The technique for obtaining the statistical measurements employs a specially developed photographic

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method which requires no instrument installation in the aircraft and permits rapid data reduction together with good accuracy. (See ref. 1.)

Previous preliminary results on some landing contact conditions obtained by this method were presented for commercial transport airplanes during routine daytime operations at the Washington National Airport (ref. 2). The project has been continued, and the number of measurements has been increased to what appears to be a sufficiently large sample in order to allow some separation of data for investigating the influence of certain factors on the contact conditions (ref. 3). In addition to the data for the transports, measurements have been obtained for Boeing B-47 jet bombers and Boeing KC-97 tankers at Barksdale Air Force Base and for Convair B-36 bombers at Carswell Air Force Base, which were obtained with the cooperation of the Strategic Air Command.

RESULTS AND DISCUSSION

The measurements in most cases included vertical velocity, forward speed, bank angle, and rolling velocity at the instant before landing contact. The discussion will be confined to vertical velocity and forward speed since these quantities have the most direct influence on the vertical and drag loads produced in the landing gear.

Effects of Gusts

One factor which was believed to be important in its effect on the contact conditions was the turbulence of the air. Figure 1 shows the results obtained by separating the center-of-gravity vertical-velocity data for the transport airplanes according to whether the wind was gusty or not gusty. The gusty condition is defined by the U. S. Weather Bureau as sudden intermittent increases in speed with at least a 10-mph variation between peaks and lulls, the peaks reaching at least 18 mph and the average time interval between peaks and lulls usually not exceeding 20 seconds. The figure shows curves of the probability of equaling or exceeding given center-of-gravity vertical velocities obtained by fitting Pearson Type III probability curves to the measured data.

The mean vertical velocities $\bar{V}_V$ were 1.22 fps without gusts and 1.50 fps with gusts, and this difference is statistically significant. Comparison of the gusty and nongusty condition indicates that for a given number of landings the vertical velocity likely to be equaled or exceeded is about 25 percent greater for the condition with gusts than for the condition without gusts. The values of vertical velocity likely to be equaled or exceeded in 1,000 landings are 3.5 fps and 4.7 fps for the nongusty and gusty conditions, respectively.

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Inasmuch as the tests were conducted during clear weather conditions, the gust effect shown is due to gust intensities occurring in clear air at the ground and does not include the extreme gust intensities associated with squalls and other storm conditions. On the average, the high relative frequency of occurrence of gusts and no gusts, indicated by the number of landings for the two conditions during the tests, was much greater than would normally be expected. An analysis of the hourly sequence reports of the U. S. Weather Bureau at Langley Air Force Base for a 5-year period indicated that the relative frequency of occurrence of the gusty condition was about 1 to 20. Thus, over a long period of time, for instance, the life of a given airplane, the solid curve for the condition without gusts is the one to be considered as representative of the condition likely to be encountered about 95 percent of the time and the dashed curve for the gusty condition, the other 5 percent. The number of landings are given for the probability curves as an indication of their reliability. A comparison of the probability curves of vertical velocity determined from the data of the first 60 landings for all airplanes, and then successively for 126, 243, and 478 landings as more landings were photographed, indicated that possibly on the order of 200 landings are required to establish a probability curve which will have a practical degree of reliability.

Comparison of Vertical Velocities at First and Second Contacts

Although the vertical velocity of the center of gravity of an airplane generally characterizes the severity of the landing, most landings are not symmetrical and the load produced in the landing gear is dependent on the vertical velocity at the landing gear itself. A theoretical study contained in reference 4 indicated that there could be substantial differences in the vertical velocity of the first gear truck to contact and in subsequent contacts by the other trucks depending on the attitude and angular velocities of the airplane, on the amount of lift, and on the configuration and inertia characteristics.

One factor involved is the ratio of the semitread to the rolling radius of gyration. Presented in figure 2 is a comparison of the vertical-velocity probability curves obtained from the measured data for the first and second truck contacts for the transport landings, separated into four-engine and two-engine categories, since the values of the ratio of semitread y_t to rolling radius of gyration k_X of 0.7 to 0.8 for the four-engine airplane and 1.0 to 1.2 for the two-engine airplane are appreciably different for these airplane types. The theoretical analysis of reference 4 indicated that, other factors being the same, the ratio of vertical velocities for the second wheel to contact to the first wheel to contact should vary approximately as this parameter $\frac{y_t}{k_X}$. Thus, for the four-engine airplane, the vertical velocity for the second wheel to contact should be about 25 percent less than that for the first wheel, whereas, for the two-engine aircraft, the vertical velocity for the second wheel to contact should be about 10 percent greater than that for the first. The curves in the figure established by the experimental data indicate essentially no difference in the probability for equaling or exceeding a given vertical velocity between the first and second wheel to contact for either the four-engine or the two-engine category. Apparently, the effect is masked by other factors such as bank angles and rolling velocities at initial contact, side drift, landing-gear energy-dissipation efficiency, and so forth.

Probability Curves

Presented in figure 3 are the probability curves for 222 landings of the B-47 jet bomber, 59 landings of the KC-97 tanker, and 144 landings of the B-36 bomber. Also shown for comparison with the NACA B-47 data are the data for 215 landings of a B-47 bomber which were obtained by the Boeing Aircraft Corporation. The mean values of vertical velocity for the two sets of B-47 data are essentially identical, 1.97 fps and 2.00 fps for the NACA and Boeing data, respectively, and the probability curves, the solid and short-dashed lines, show good agreement.

The fact that there is good agreement for these vertical-velocity probability curves established from data obtained by different methods and at different locations not only attests to the accuracy of the two methods but also further substantiates the statement made previously that on the order of 200 landings are sufficient to establish a reliable probability curve. The mean vertical velocity for the B-36 landings is 2.29 fps, and this curve (long-dashed) indicates somewhat higher probabilities for equaling or exceeding a given vertical velocity than those for the B-47 results. The values of vertical velocity likely to be equaled or exceeded once in 1,000 landings for the KC-97, B-47, and B-36 airplanes are 5.5 fps, 6 fps, and 7 fps, respectively. It should be noted that the measurements for the tankers and bombers were obtained during continuous day-to-day operations (daylight hours only), and the relative frequency of occurrence of gusts to no gusts was about 1 to 30 for the KC-97 and B-47 airplanes and about 1 to 3 for the B-36 airplane. Thus, the results for these airplanes, particularly for the KC-97 and B-47 airplanes, would be more comparable to the transport probability curve for the condition without gusts, which indicates that an average vertical velocity for all transports of about 3.5 fps would be equaled or exceeded once in 1,000 landings.

In figure 4 is shown a comparison of the probability curves of vertical velocity for various types of airplanes identified by approximate landing weight W in pounds. The mean vertical velocity in feet per second for each type is also given. The landing weights are shown only to give a rough indication of the class of airplanes involved.

Although the results suggest a trend toward increasing vertical velocity with increasing landing weight, it will be noted that the heaviest airplanes shown are all military types, and the lighter ones are commercial transports, so that the major influence on the vertical velocities may be the type of operations rather than the weight. This plot is presented in order to show a cross section of most of the currently available vertical-velocity probability curves for routine daytime operations of current land-based airplanes and to indicate that there are substantial and significant differences. The quantity of data is as yet insufficient to permit determination of the factors which account for the differences in landing statistics for various types of airplanes in a given type of operation.

Airspeed at Contact

Another landing contact condition for which statistical data have been obtained is the airspeed at contact, obtained by combining the component of wind parallel to the line of flight and the measured ground speed. The results are shown in figure 5 as curves of the probability of equaling or exceeding various percentages above the stalling speed. The solid curve is for the B-36 airplanes, the short-dashed curve for the B-47 airplanes, and the long-dashed curve for the commercial transports. The stalling speeds are based on estimated weights of the airplanes at landing and may involve some error. The mean airspeeds at contact expressed as percent above the stall are 19 percent for the B-36 airplanes, 23 percent for the B-47 airplanes, and 29 percent for the transports.

For the B-36 airplanes, one out of a thousand will land with a speed about 50 percent above the stall. For the transports, one out of a thousand will land with a speed about 60 percent above the stall, or about 20 percent higher with respect to stall speed than the B-36 airplanes. Although the mean landing speed (23 percent above the stall) for the jet-propelled B-47 bomber was between those of the other two cases shown, the probability for a higher landing speed occurring for this airplane was greater. The results indicate that in 1,000 B-47 landings, one landing will be made at a speed at least 70 percent above the stall. Analysis of the transport data with regard to the effect of gusts on airspeed at contact indicated no effect due to gusts as contrasted to the substantial effect of gusts on vertical velocity. The reason for the absence of an effect on the landing speed due to gusts may be that the airplanes normally land so fast that there is sufficient margin above the stall to take care of the gusty condition.

CONCLUDING REMARKS

The statistical analysis of the transport landings indicated that the gusty wind condition had a significant effect in increasing the vertical velocity likely to be equaled or exceeded in a given number of landings. One out of 1,000 landings will equal or exceed a vertical velocity of 3.5 fps and 4.7 fps for the nongusty and gusty conditions, respectively, or an increase of about 25 percent due to gustiness. It appears likely, however, that on the average the curves for the condition without gusts represents the more probable condition. The relative frequency of occurrence of gusts to no gusts was found to be 1 to 20 for a 5-year period at the Langley Air Force Base.

The values of vertical velocity likely to be equaled or exceeded once in 1,000 landings of routine operations of tankers and bombers were 5.5 fps for the KC-97 tankers, 6 fps for the B-47 jet bombers, and 7 fps for the B-36 bombers. These results are comparable to the transport probability curve for the condition without gusts, which indicates that an average vertical velocity for all transports of about 3.5 fps would be equaled or exceeded once in 1,000 landings.

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Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., May 3, 1955.

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EFFECT OF GUSTS ON VERTICAL VELOCITY AT CONTACT FOR TRANSPORT AIRCRAFT

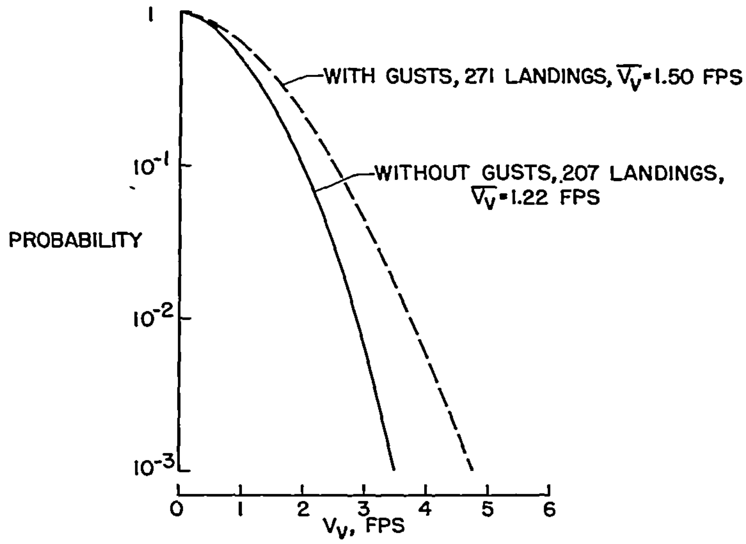

Figure 1

COMPARISON OF VERTICAL VELOCITIES AT FIRST AND SECOND CONTACT

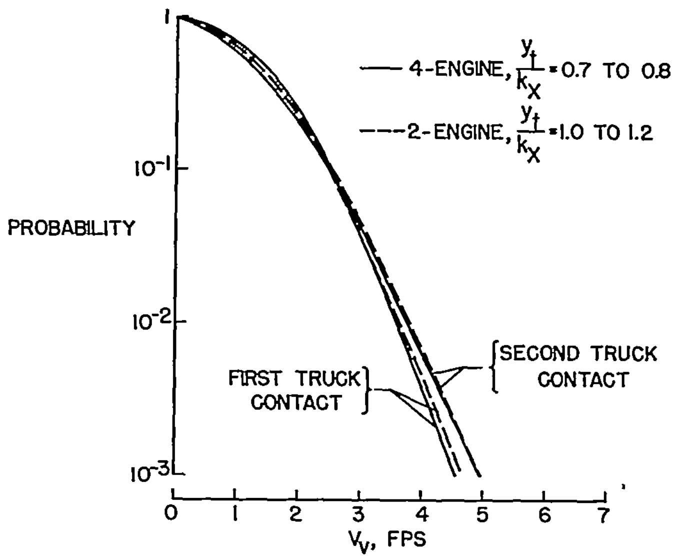

Figure 2

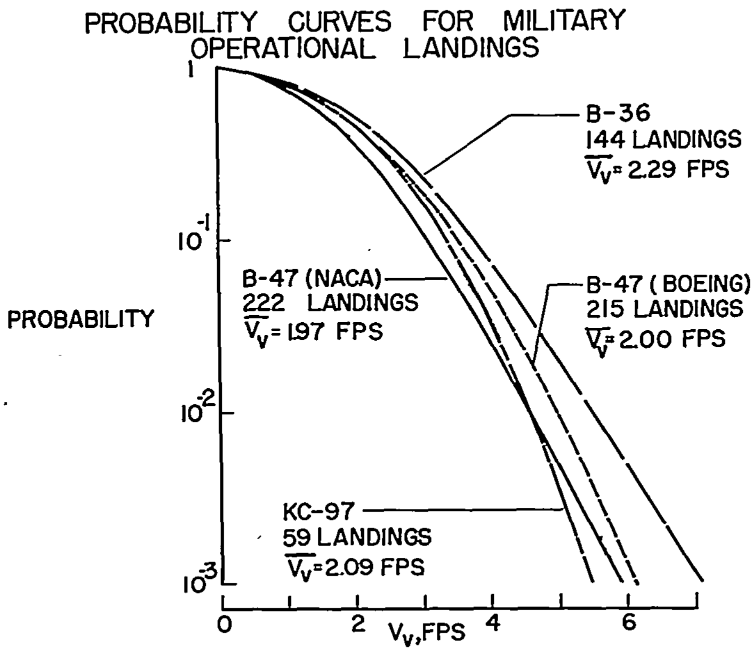

Figure 3

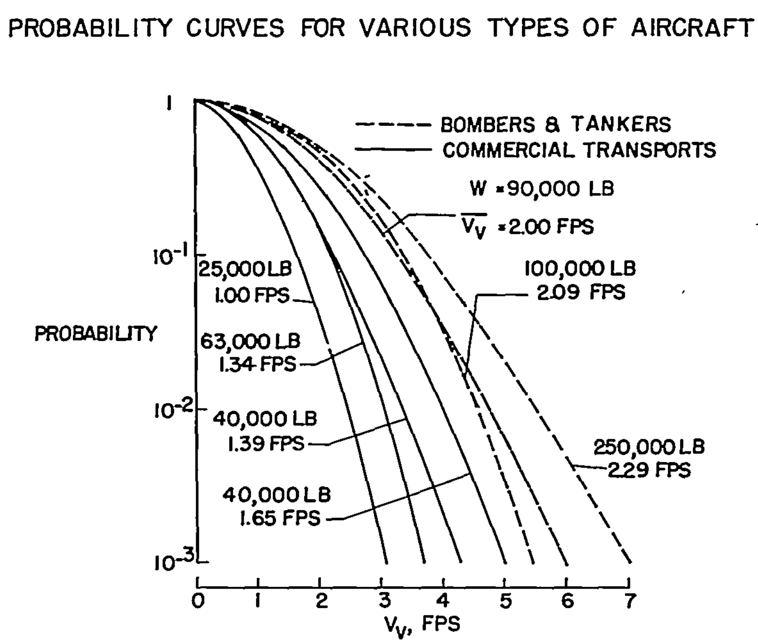

Figure 4

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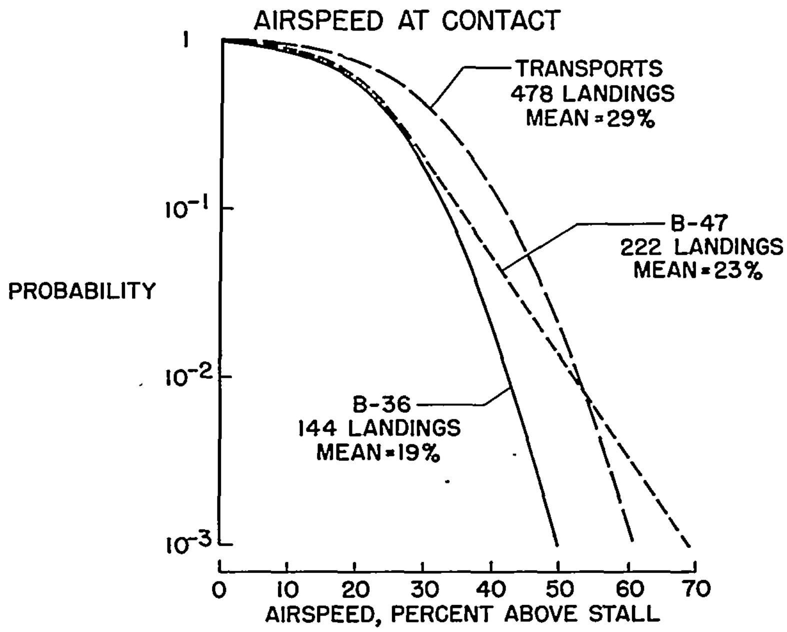

Figure 5

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